DEVELOPING ONE-OF-A-KIND COMPOSITE STRUCTURES FOR SCIENCE AND EXPLORATION AT NASA'S GODDARD SPACE FLIGHT CENTER

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NASA's Goddard Space Flight Center

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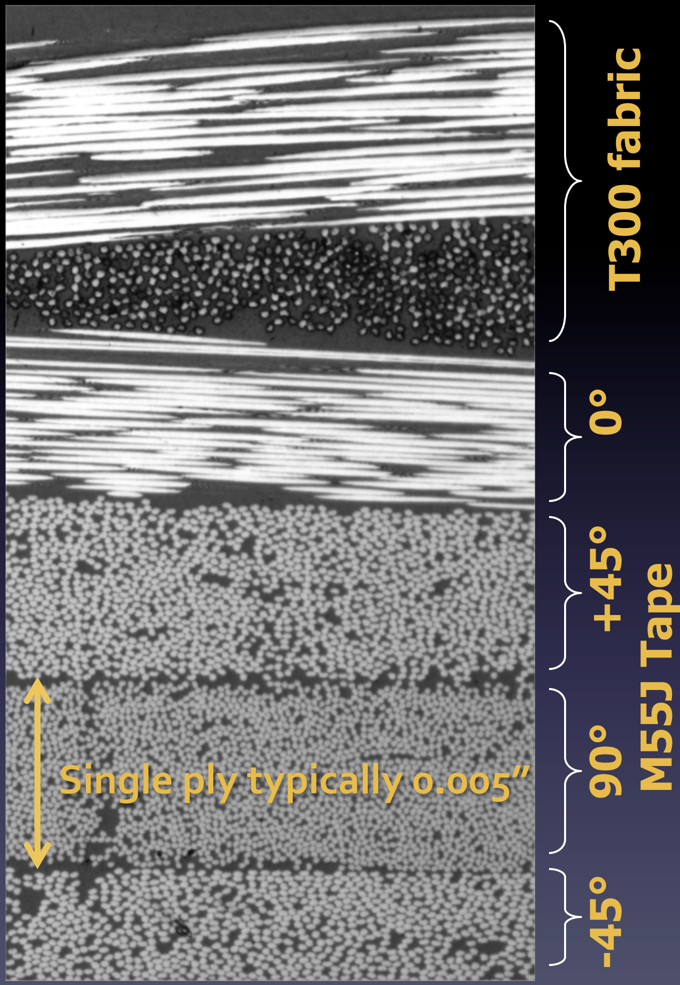
Outline

- Recent examples of composite structures designed and built by NASA and its partners
- Primary benefits of composites (carbon fiber reinforced plastics, CFRP's) for space structures
- New composite technology thrust areas at Goddard Space Flight Center (GSFC)

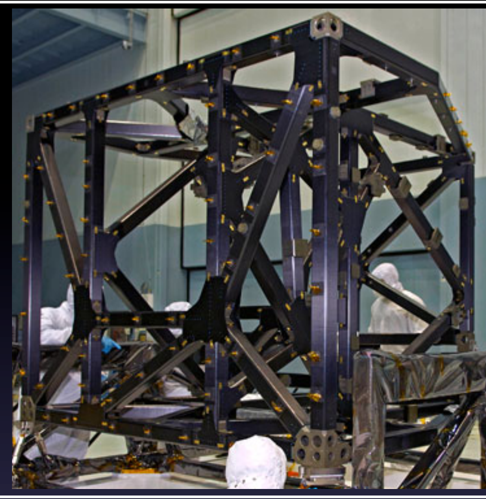
Common CFRP's for Space Applications

- Materials supplied as fiber pre-impregnated with resin , "prepreg", with fiber volume ~60% for tape and ~57% for fabric
- Unidirectional tape:
  - M55J fiber:
    - industry standard, good combination of stiffness and strength
  - Cyanate ester resin
    - 954-3 or RS-3
    - 350°F cure
    - low moisture absorption(~10% of epoxy)
- Biaxial fabric:
  - T300 fiber/cyanate ester resin
    - industry standard, high tensile and shear strength
    - plain weave fabric for simplicity and cost
- Two primary layups used:
  - Quasi-isotropic (QI) for omnidirectional loading and low distortion, e.g. $[0/45/90/-45]_s$
  - Biased layup for unidirectional loading and low distortion, e.g. $[0_3/45/0_2/-45]_s$



Quasi-isotropic tape w/ fabric outer plies

Recently Developed Composite Structures

Program	HST's Super Lightweight Interchangeable Carrier (SLIC)	JWST's Integrated Science Instrument Module (ISIM)	NESC's Composite Crew Module (CCM)
Configuration			
Type	Protoflight	Protoflight	Prototype
Flight	STS-125	Ariane V	Designed for Ares I
Composite benefit	Specific Stiffness	Thermal Distortion	Optimized load paths and biaxial tensile strength
Technology highlights	•Titanium metal matrix/integral end fitting struts •Human-rated primary structure	•Cryogenic joinery •Hybrid laminates for "zero" CTE at cryogenic temperature	•OOA 3D woven pi-preforms •OOA splice joint •Membrane loaded pressure dome

PRIMARY BENEFITS OF COMPOSITE FOR SPACE APPLICATIONS

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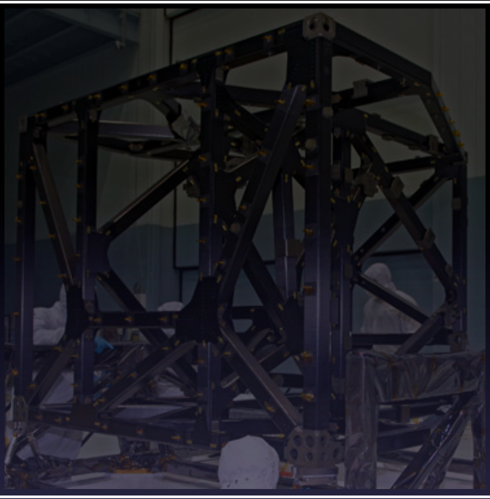
Configuration			
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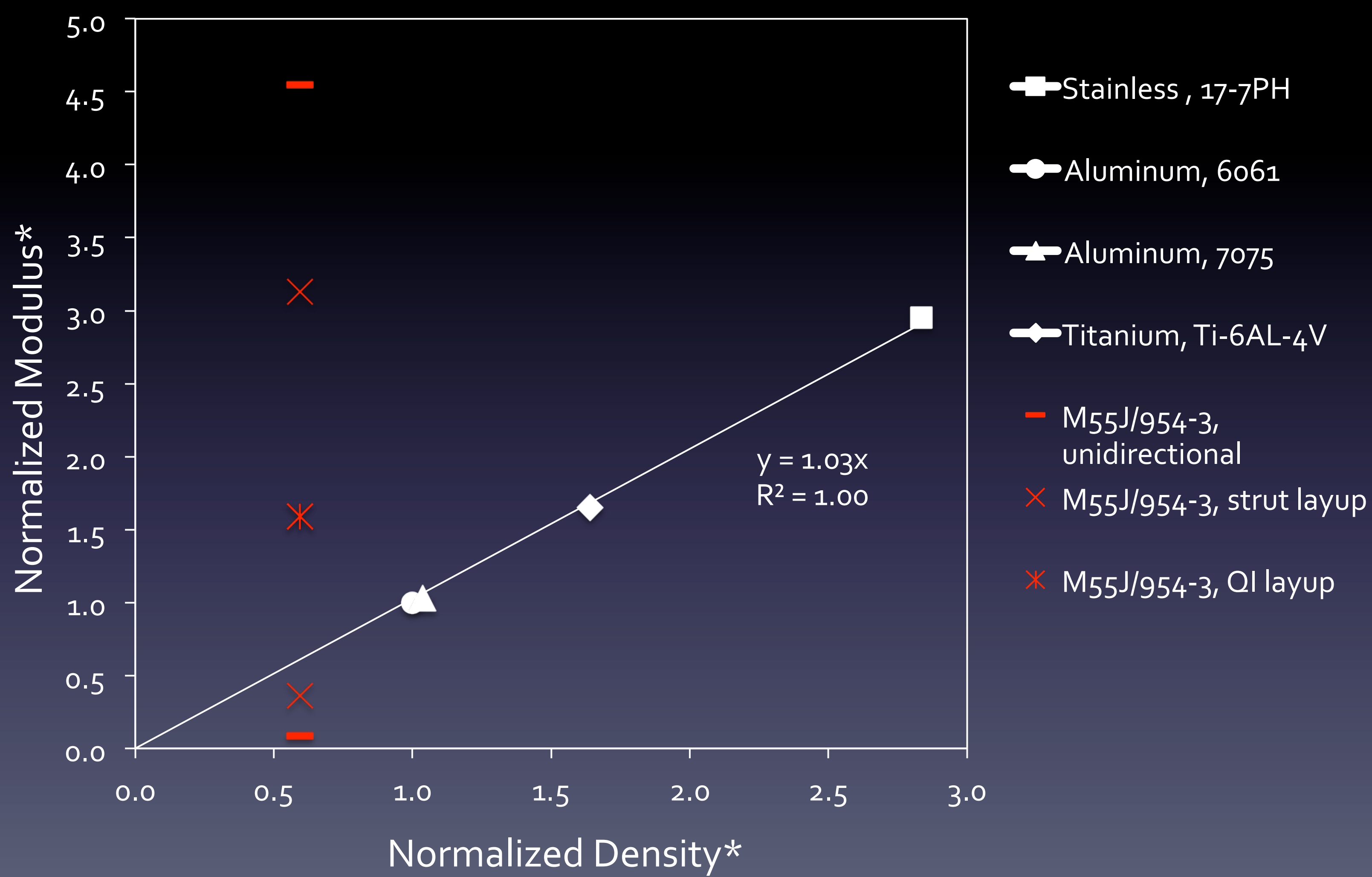
Specific Stiffness

- As a preliminary metric, specific stiffness (modulus/density) is a good selection criteria for stiffness critical applications, such as struts and booms.

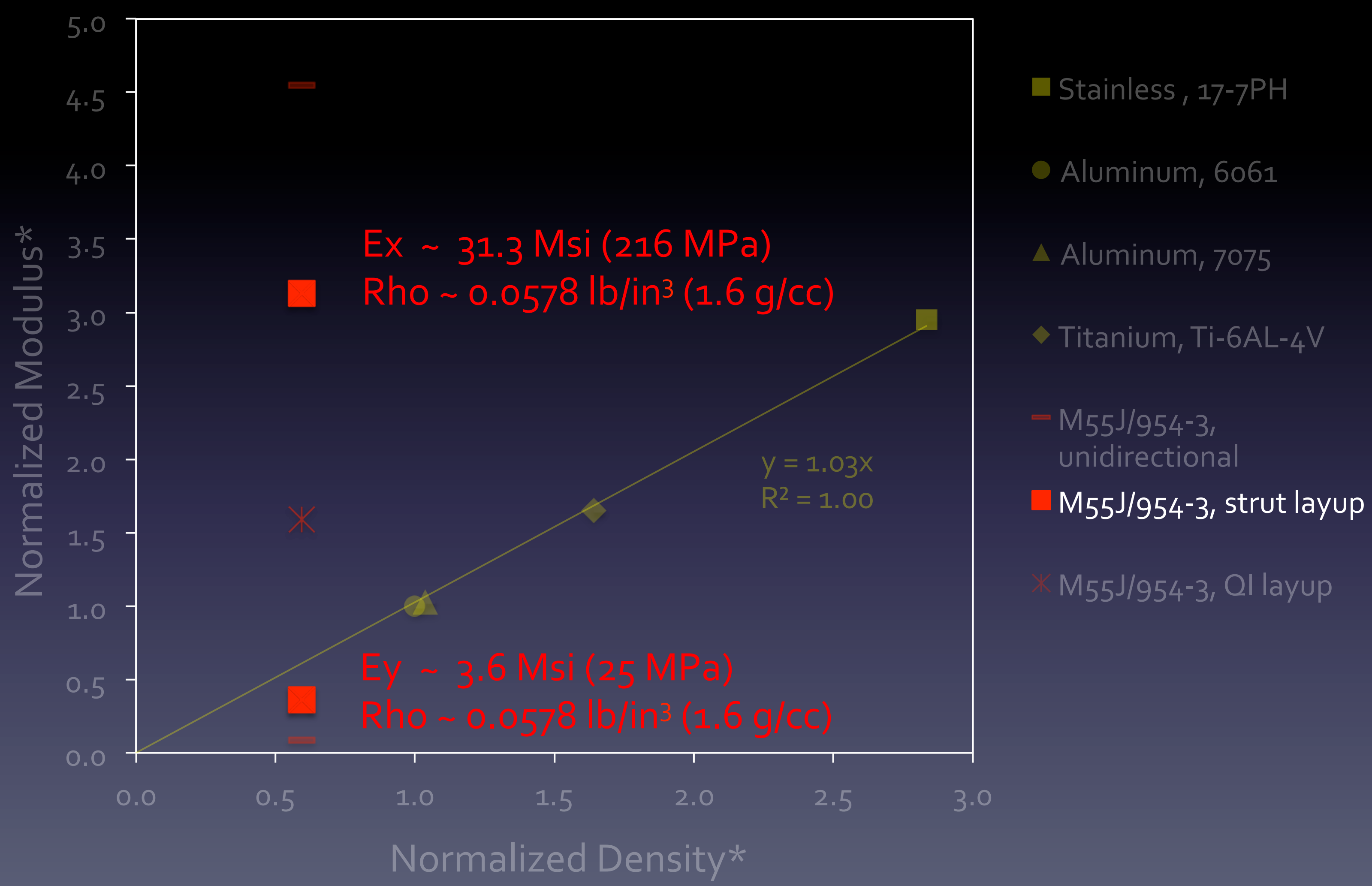
- For composites, one must carefully consider the type of loading, unidirectional vs omnidirectional, when evaluating design options, due to their anisotropic nature.

Specific Stiffness



*normalized by Aluminum 6061 properties

Specific Stiffness



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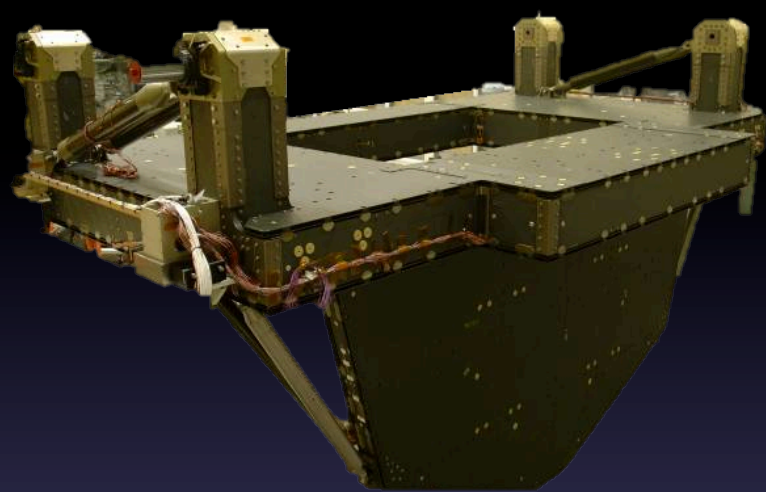
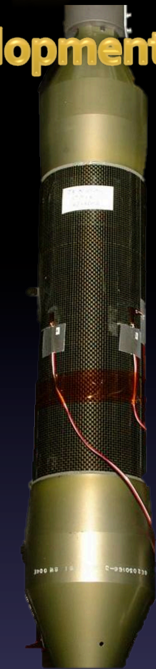
Strut Application

SLIC Flight Structure

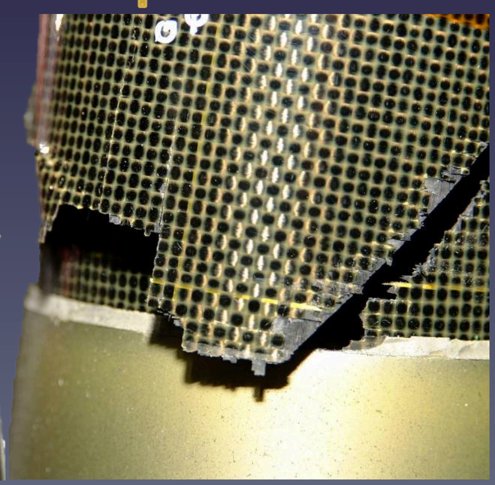


Development Testing



Tension Failure

Compression Failure



- For strut application
  - Often required to limit deflections
  - E*A becomes a critical design constraint

- For equivalent E*A designs:
  - Composite = 0.06 lb/in (3 lb per 52 in)*
  - Metallic (Al or Ti-6-4) = 0.31 lb/in (16lb per 52 in)*

*does not account for end details

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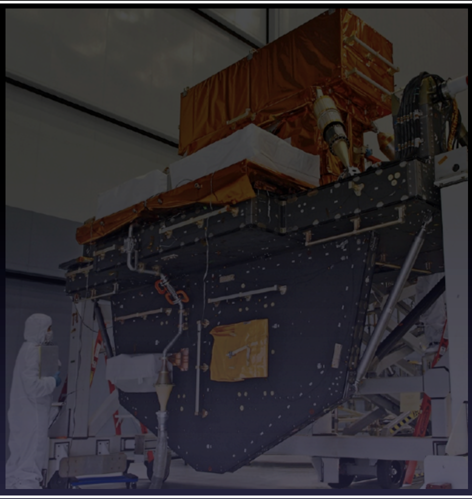
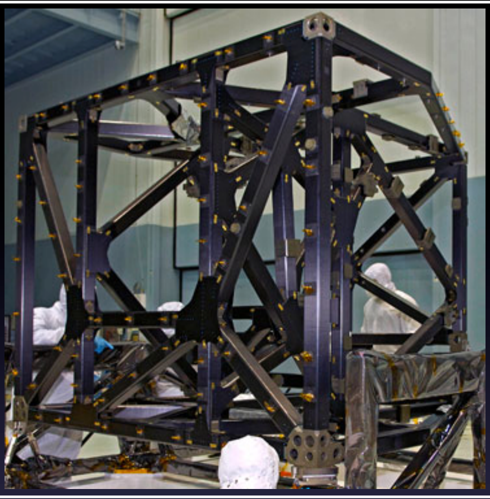
Configuration			
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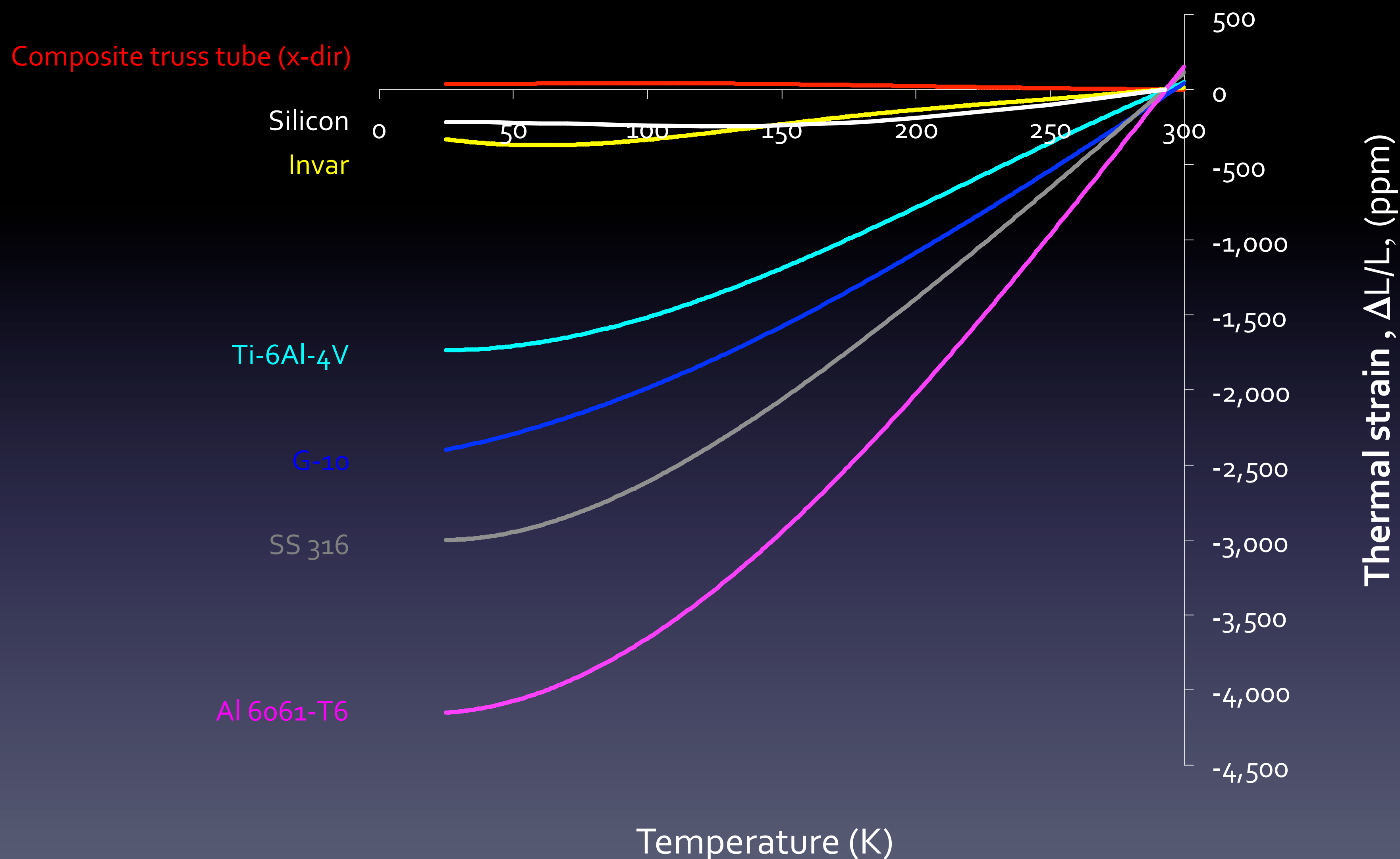
Coefficient Of Thermal Expansion (CTE)

- For optical metering structures, a low thermal expansion coefficient is often required or eliminates the need for active thermal control

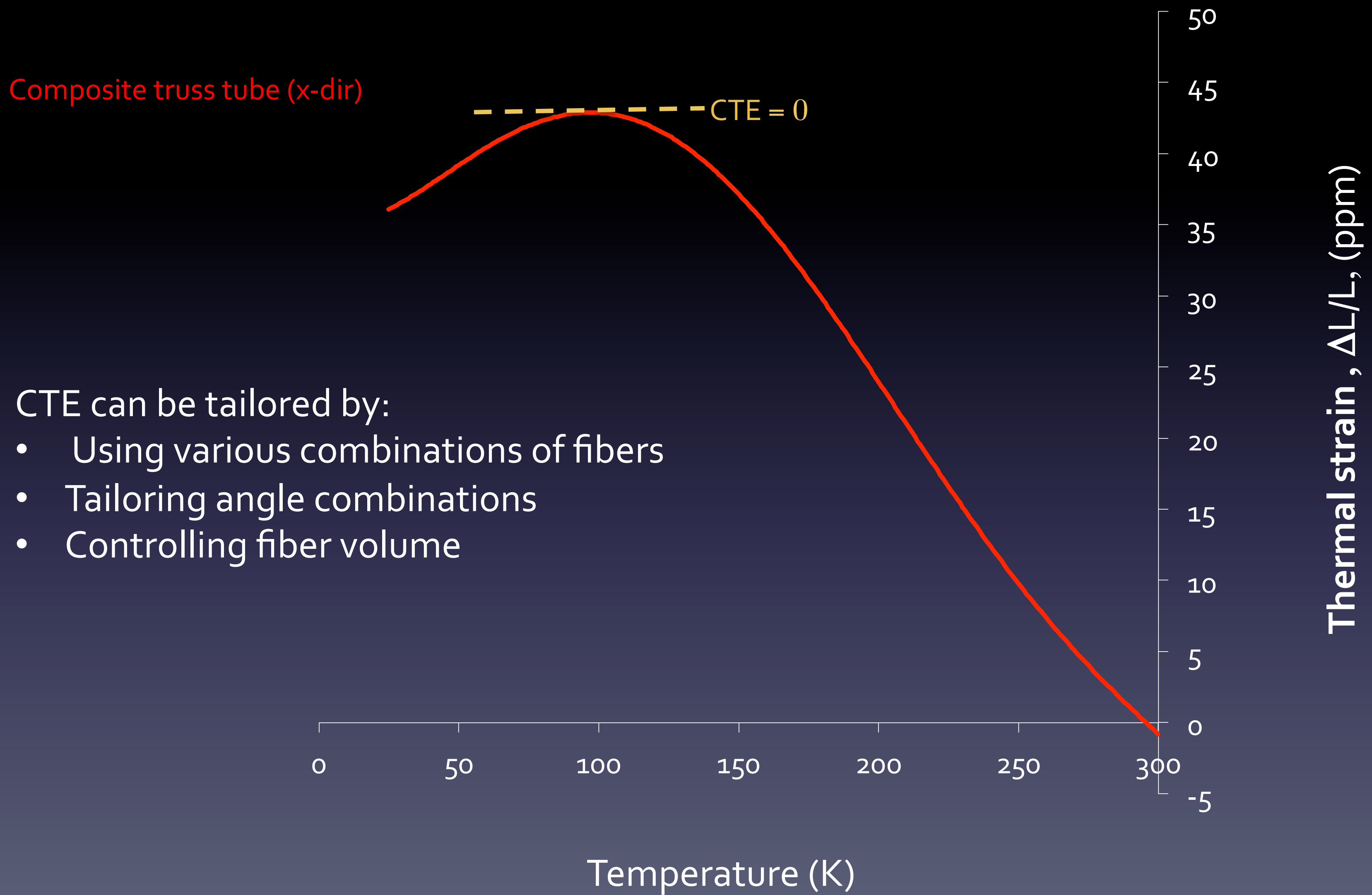
- Composite materials not only have low thermal expansion but it can be tailored based on the operational temperature needs of the observatory

Coefficient Of Thermal Expansion (CTE)



CTE = slope of ΔL/L vs T curve

Coefficient Of Thermal Expansion (CTE)



CTE can be tailored by:

- Using various combinations of fibers
- Tailoring angle combinations
- Controlling fiber volume

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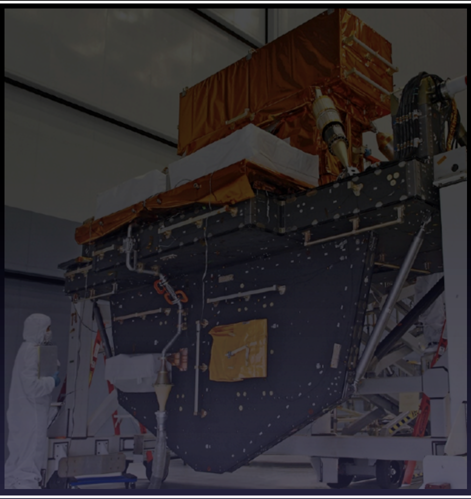
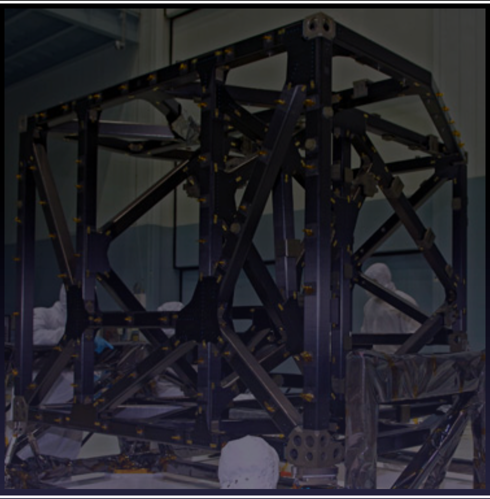
Configuration			
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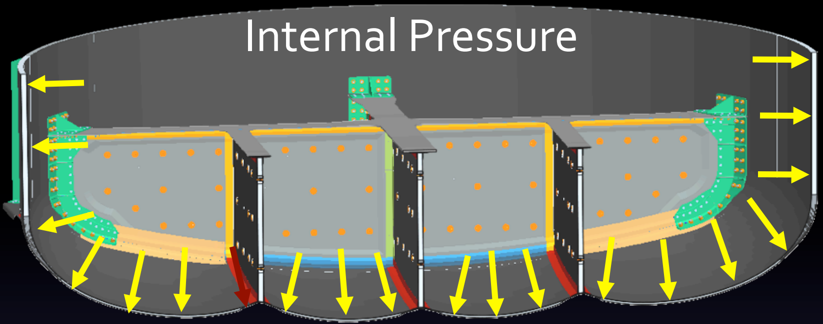
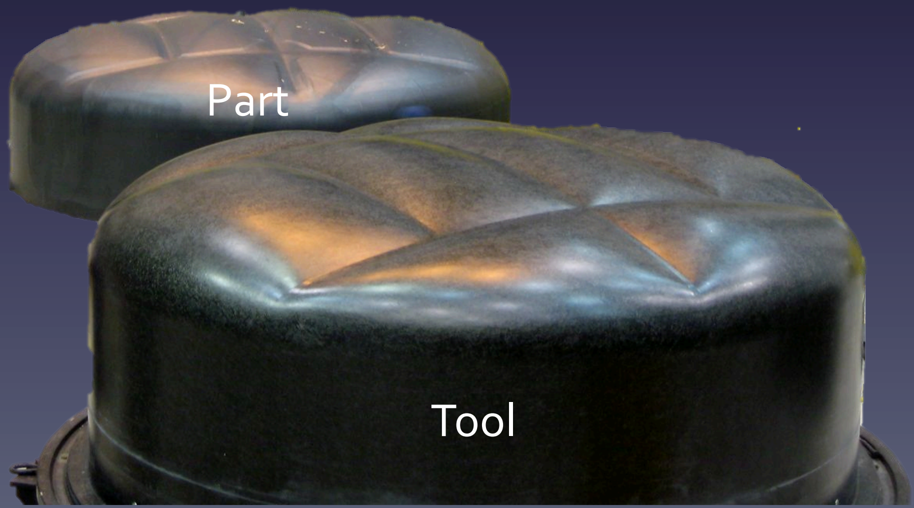
Optimized Load Path

- Composites offer two unique properties that allow a designer to optimize the load path:
  - fiber orientation tailoring
  - forming complex contours easily/affordably

Optimized Load Path

- Backbone carries pressure load (no ring frame)
- Membrane pressure head lobe shapes



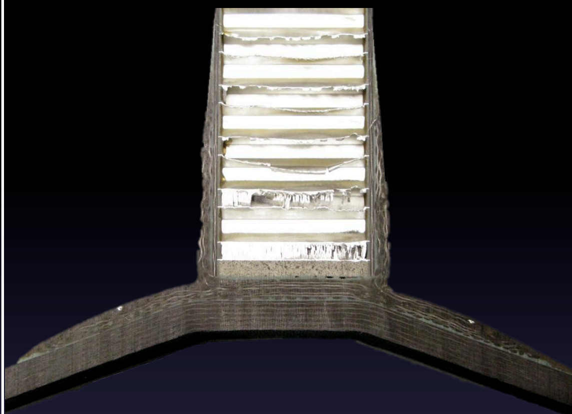
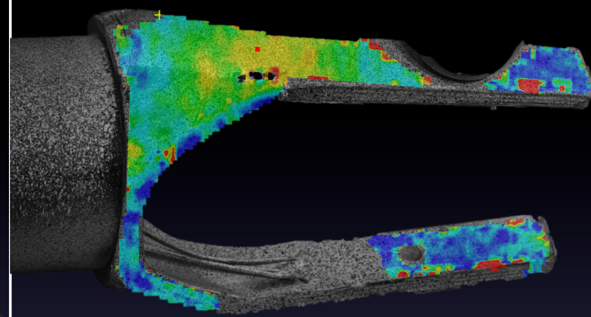
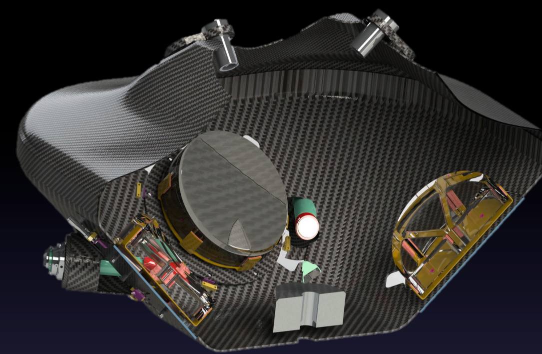


Other Primary Benefits of Composites for Spacecraft applications

- Demisable for re-entry requirements
- Minimized interference for electromagnetic-sensitive instruments/applicatoins
- High or low thermal (fiber dependent) conductivity along primary structural load paths for thermal management

COMPOSITE TECHNOLOGY THRUST AREAS FOR SPACE APPLICATIONS

Technology Thrust Areas

Thrust Area	Composite Joints	Development Cycle	Monocoque construction
Configuration			
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Composite benefit	• CTE matched joint • Mass savings • Performance enhancement	• Reduction in "art-to-part" cycle time	• Reduced part count • Optimized load path
Technology highlights	• 3D woven joining	•Out-of-Autoclave construction •Full-field strain correlation	•FiberSIM-to-FEA •Soft-tool assembly process

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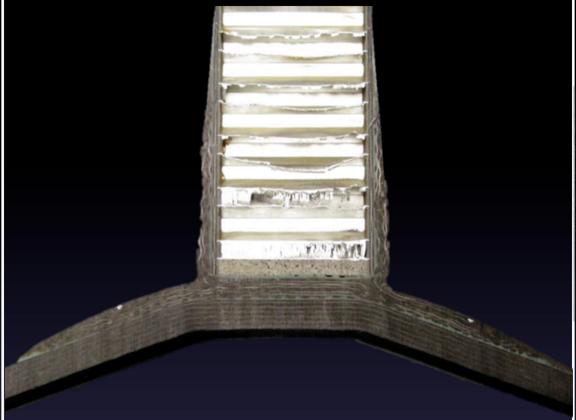
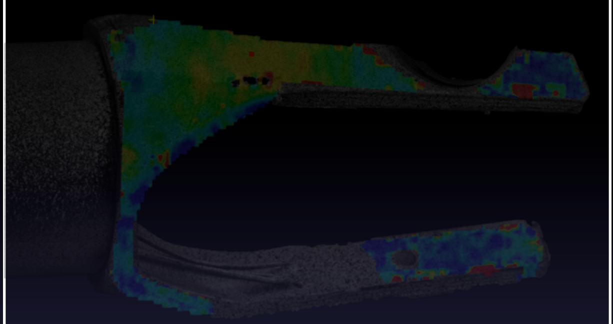
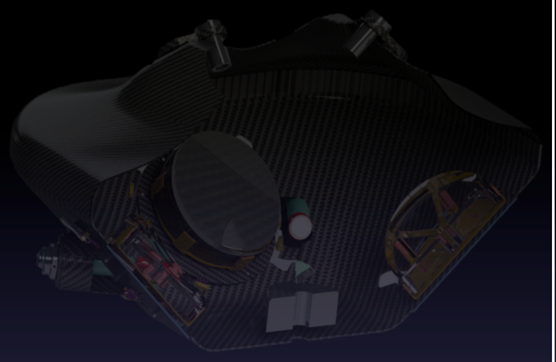
Configuration			
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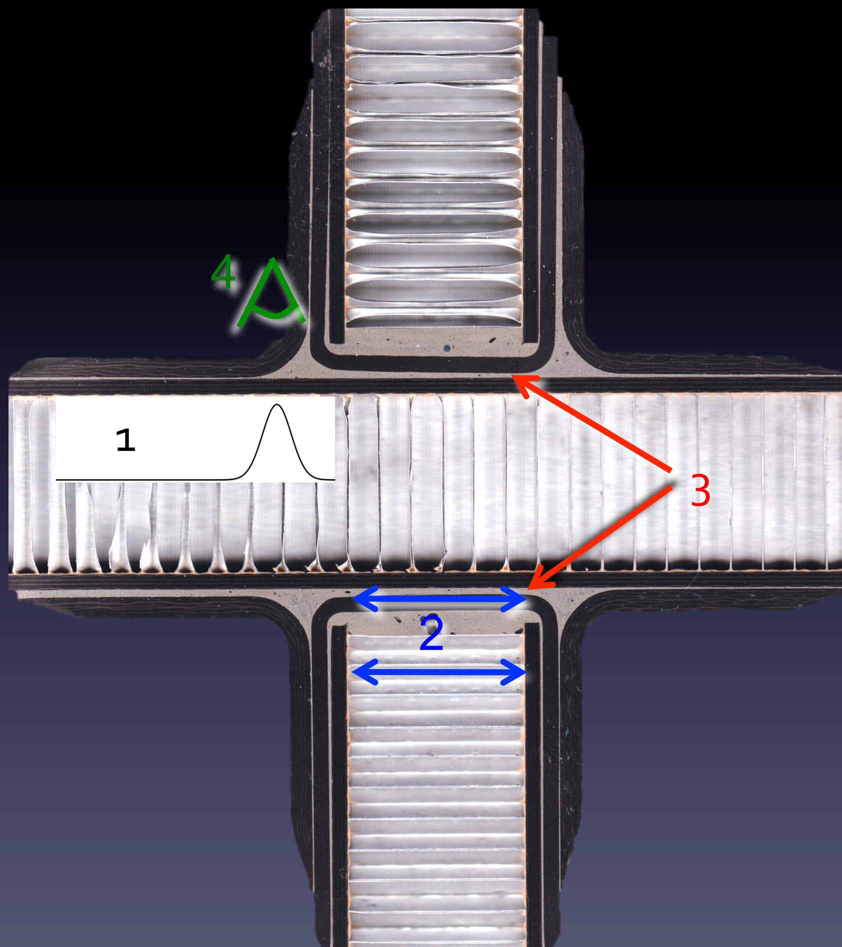
Composite Joints: The Orthogonal Joint Challenge

1. **Design Constraint**: This type of joint loads a composite laminate or sandwich in its weak direction (though-thickness tension).

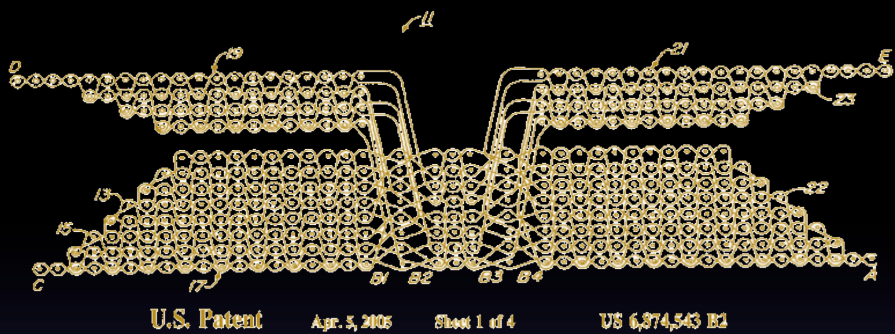
2. **Analysis constraint**: This type of joint can introduce complex thermal stresses due to the orientation of the in-plane and through thickness orientations of the adjacent members.

3. **Manufacturing constraint**: Difficult to managing tolerance stack-up on large assemblies, leading to complex tooling for fully co-cured structures and/or bondline variability for pre-cured assembly.

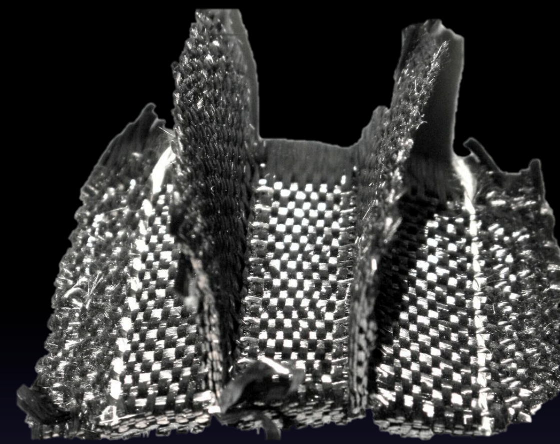
4. **NDE constraint**: The weakest part of the joint is often not inspectable (location of peak stress at L-clip corner).



Composite Joints: 3D Woven Pi Preforms



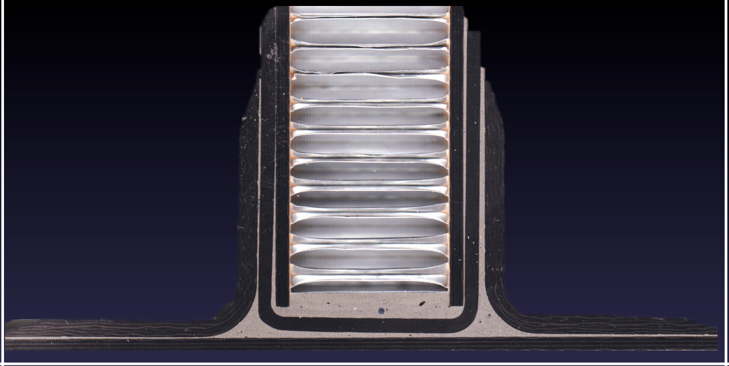
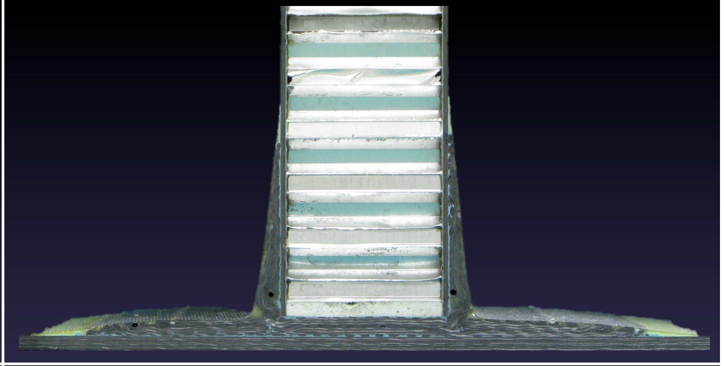
Leveraged DoD funded and Lockheed Martin's patented 3D woven pi preform



Hexcel IM7 High Strength Fiber
Bally Ribbon Mills Weave

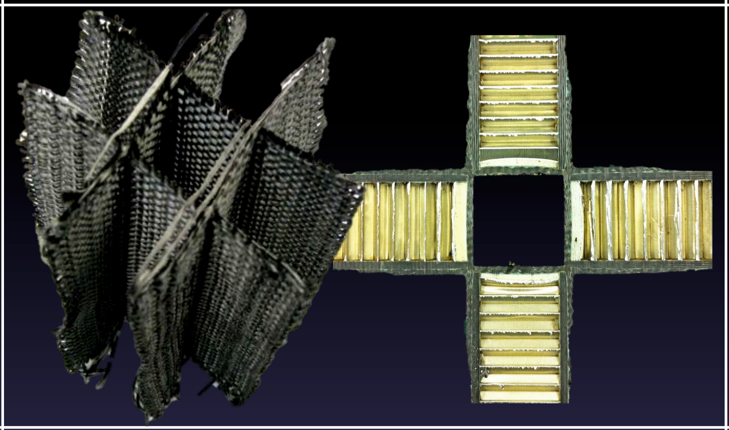
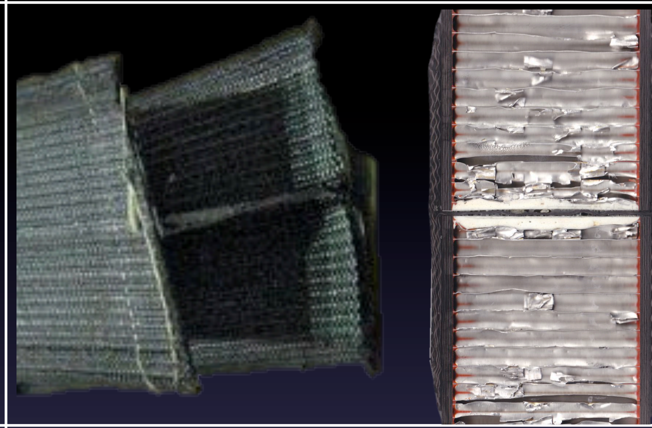
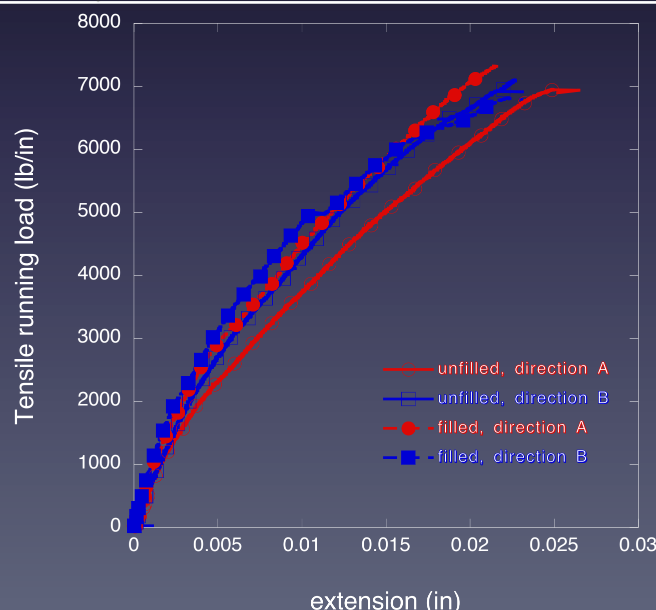
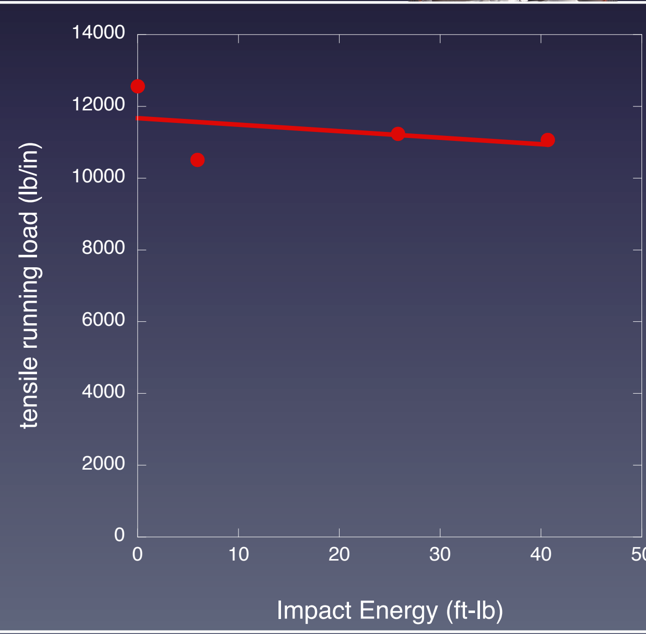
CCM Implementation on complex contoured surface

Composite Joints: Performance Comparison

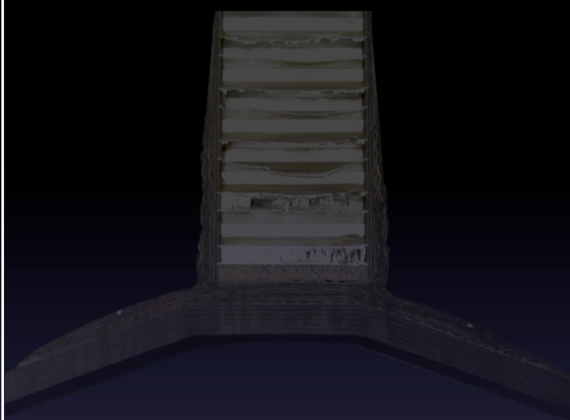
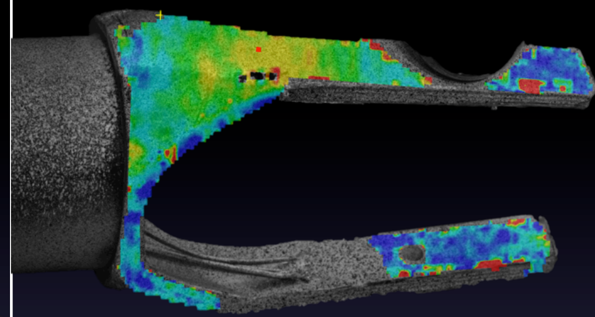
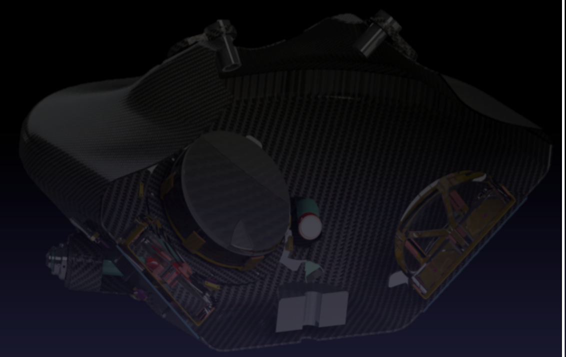
Program	HST's Super Lightweight Interchangeable Carrier	NESC's Composite Crew Module
Joint type	traditional back-to-back L-clips	3D woven pi preform
Geometry		
Pre-cured part count	5 pre-cured details: web, skin, closeout, two L-clips	2 pre-cured details: web and skin
Bonding process	2 step paste bond	1 step cobond
Tension Capability*	~900 lb/in	~2000 lb/in

*boundary condition dependent

Composite Joints: Extending 3D Woven Capabilities

Program	NESC's Composite Crew Module	Composites for Exploration
Joint type	Cruciform	H-preform
Geometry		
Performance		

Technology Thrust Areas

Thrust Area	Composite Joints	**Development Cycle**	Monocoque construction
Configuration			
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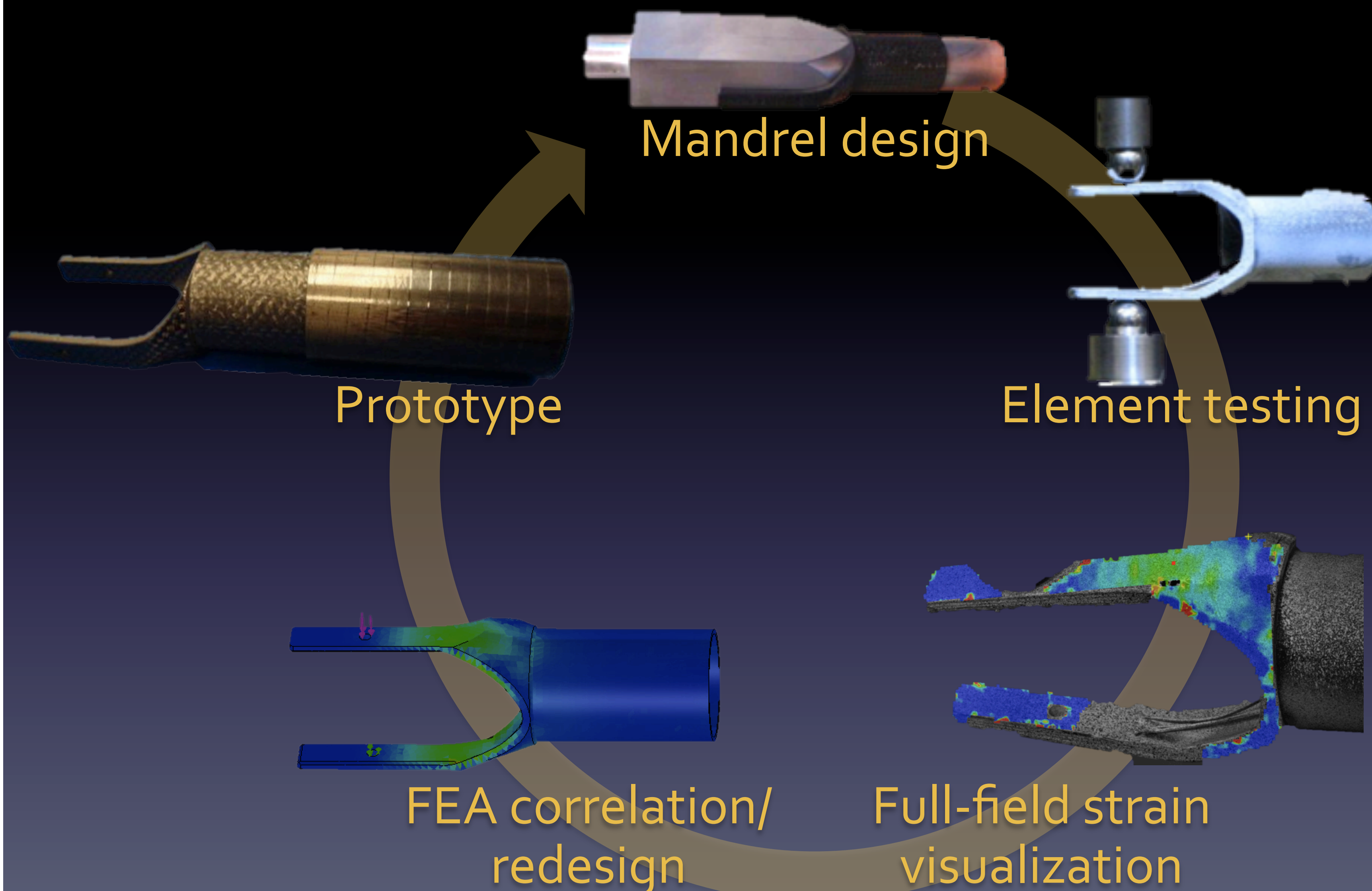
Rapid Prototyping: Reducing Development Cycle Time



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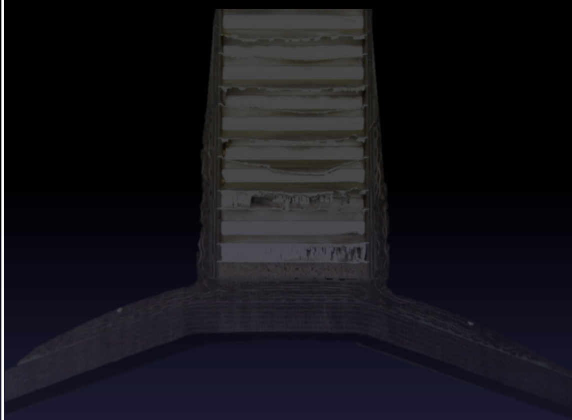
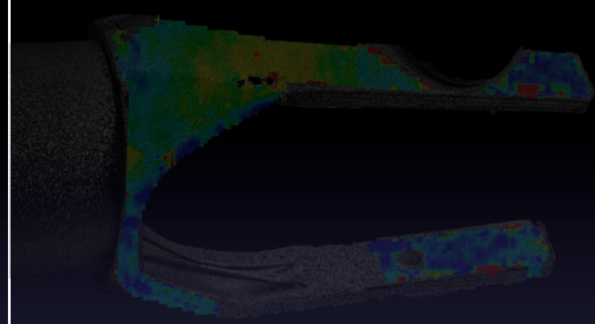
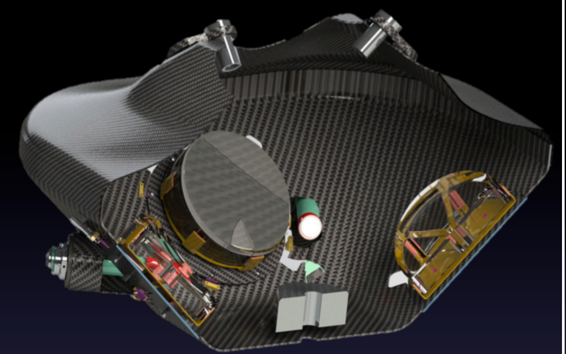
Configuration			
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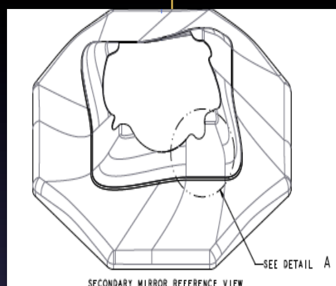
Monocoque Construction: Development Roadmap

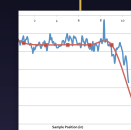


Design/Analysis

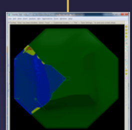
Manufacturing, Materials, and Process

In Process

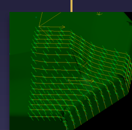
Full-scale test/ analysis correlation



Coupon correlation with simulated layups

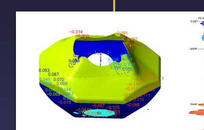


FiberSIM®-to-flat pattern

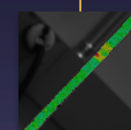


FiberSIM®-to-FEA

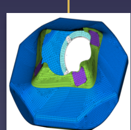
Out-of-autoclave curing



Full-field Inspection



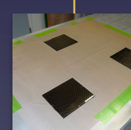
E vs position



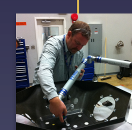
Analysis with idealized layups

In Process

Analysis with simulated layups for orientation effect



Equivalency testing



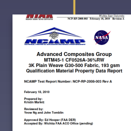
Virtual assembly tooling

In Process

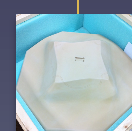
CTE vs position

In Process

Analysis with solid elements for spring-in effect



Existing material database



Low temp/low cost tooling

Low volume production (1 or 2 units) requires minimization of fixed cost investments (tooling/fixturing)

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